Chapter 8 Section I

Introduction to CDMA

CDMA: Using A New Dimension

- All CDMA users occupy the same frequency at the same time! Frequency and time are not used as discriminators
- CDMA operates by using CODING to discriminate between users
- CDMA interference comes mainly from nearby users
- Each user is a small voice in a roaring crowd -- but with a uniquely recoverable code

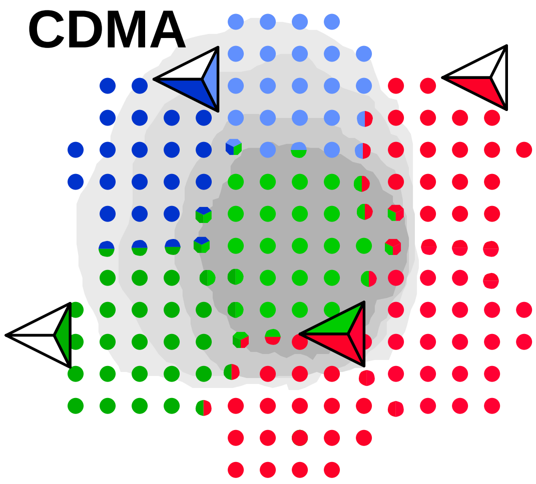


Figure of Merit: C/I
(carrier/interference ratio)
AMPS: +17 dB
TDMA: +14 to +17 dB
GSM: +7 to 9 dB.
CDMA: -10 to -17 dB.
CDMA: E_b/N_o ~+6 dB.
CDMA: E_c/I_o >-14 dB.

Raw RF of one channel vs all the energy

Our end-result Traffic Channel bit power vs noise

We watch Ec/Io because it is available – use it for deciding handoff partners

DSSS Spreading: Time-Domain View

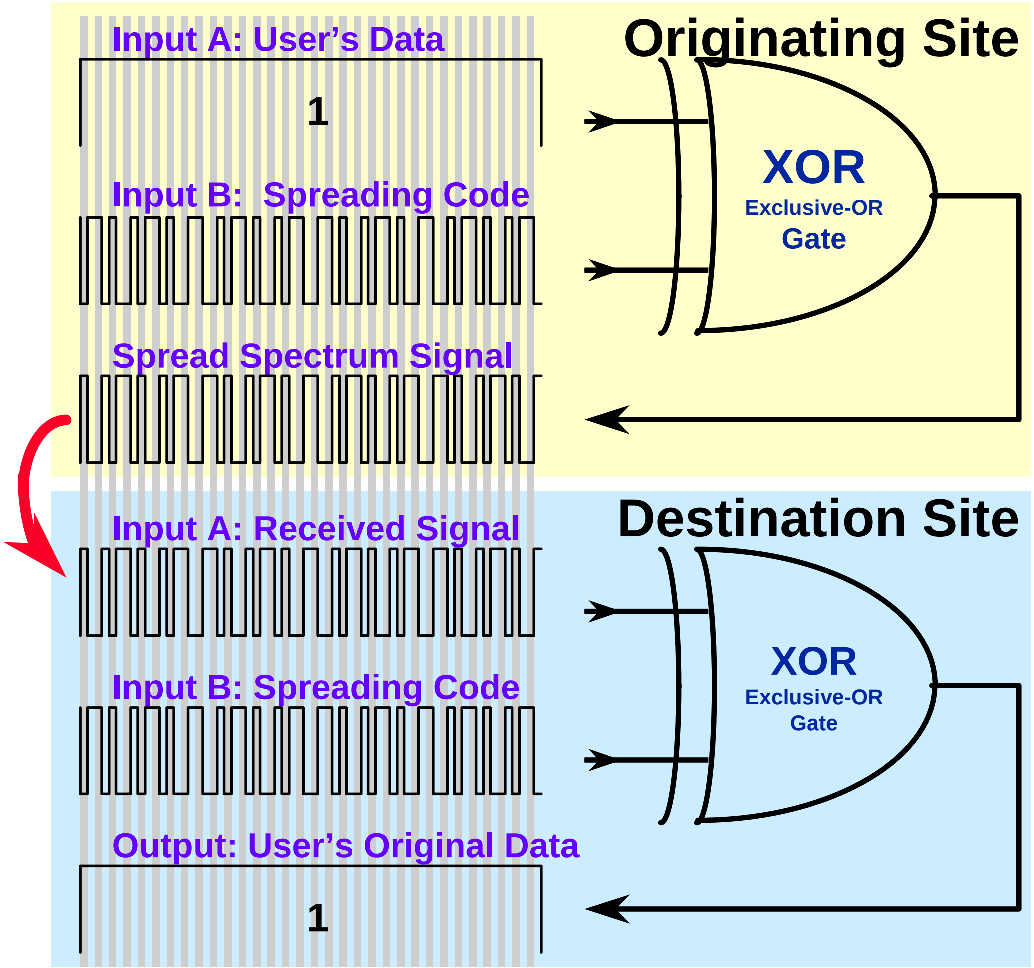
At Originating Site:

- Input A: User's Data @ 19,200 bits/second
- Input B: Walsh Code #23 @ 1.2288 Mcps
- Output: Spread spectrum signal

via air interface

At Destination Site:

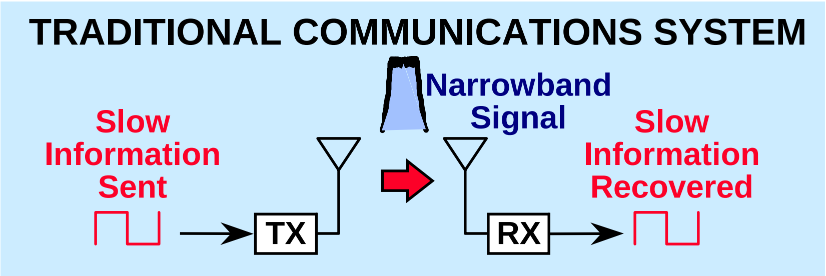
- Input A: Received spread spectrum signal
- Input B: Walsh Code #23 @ 1.2288 Mcps
- Output: User's Data @ 19,200 bits/second just as originally sent

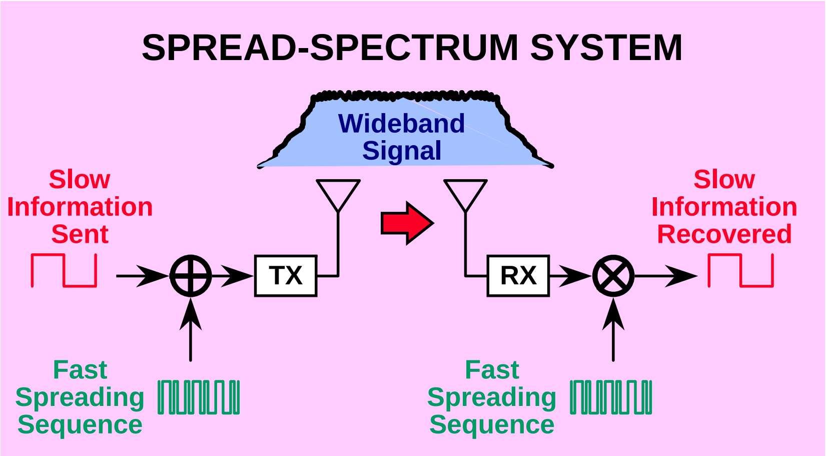


Drawn to actual scale and time alignment

Spreading from a Frequency-Domain View

- Traditional technologies try to squeeze signal into minimum required bandwidth
- CDMA uses larger bandwidth but uses resulting processing gain to increase capacity





Spread Spectrum Payoff: Processing Gain

The CDMA Spread Spectrum Benefit: Get it all in one big payment, or "Reinvest" It?

- Shannon's research says that a certain bit rate of information deserves a certain bandwidth
- If one CDMA user is carried alone by a CDMA signal, the processing gain is large - roughly 21 db for an 8k vocoder.
  - Each doubling of the number of users consumes 3 db of the processing gain
  - Somewhere above 32 users, the signal-to-noise ratio becomes undesirable and the ultimate capacity of the sector is reached
- Practical CDMA systems restrict the number of users per sector to ensure processing gain remains at usable levels

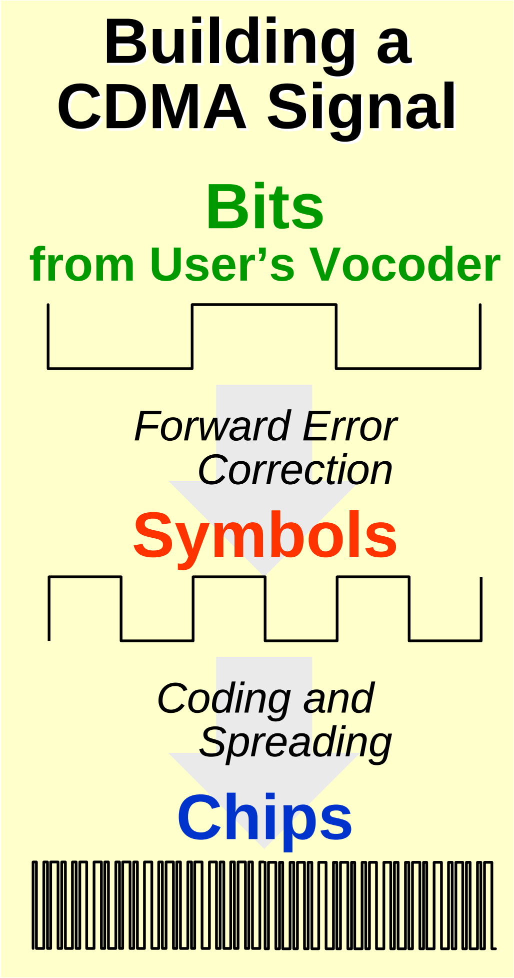
CDMA Spreading Gain

Consider a user with a 9600 bps vocoder talking on a CDMA signal 1,228,800 hz wide. The processing gain is 1,228,800/9600 = 128, which is 21 db. What happens if additional users are added?

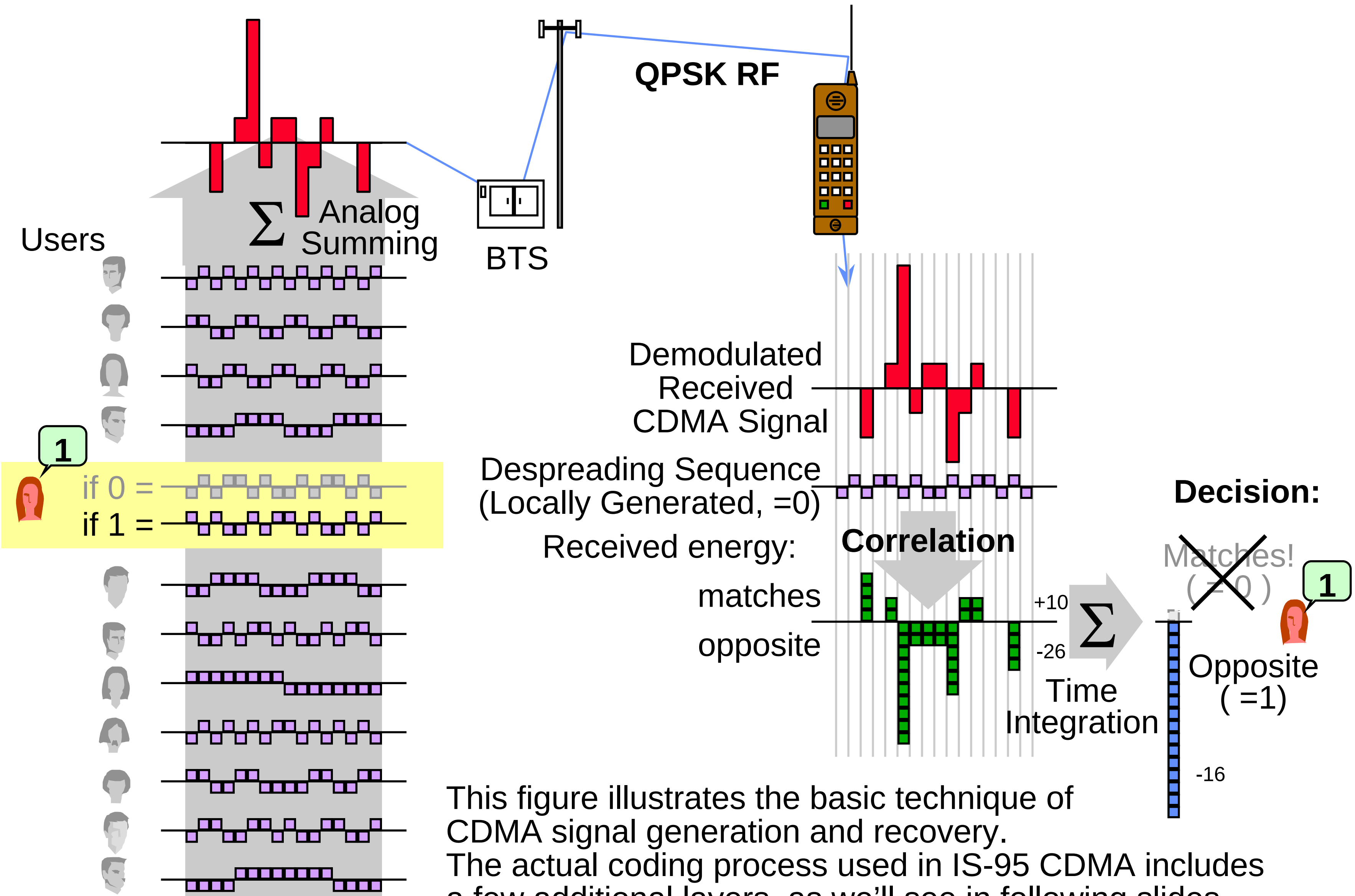
# Users	Processing Gain
1	21 db
2	18 db
4	15 db
8	12 db
16	9 db
32	6 db
64?!...maybe 32 is the right time to leave the casino	

CDMA Uses Code Channels

- A CDMA signal uses many chips to convey just one bit of information
- Each user has a unique chip pattern, in effect a code channel
- To recover a bit, integrate a large number of chips interpreted by the user's known code pattern
- Other users' code patterns appear random and integrate in a random self-canceling fashion, don't disturb the bit decoding decision being made with the proper code pattern

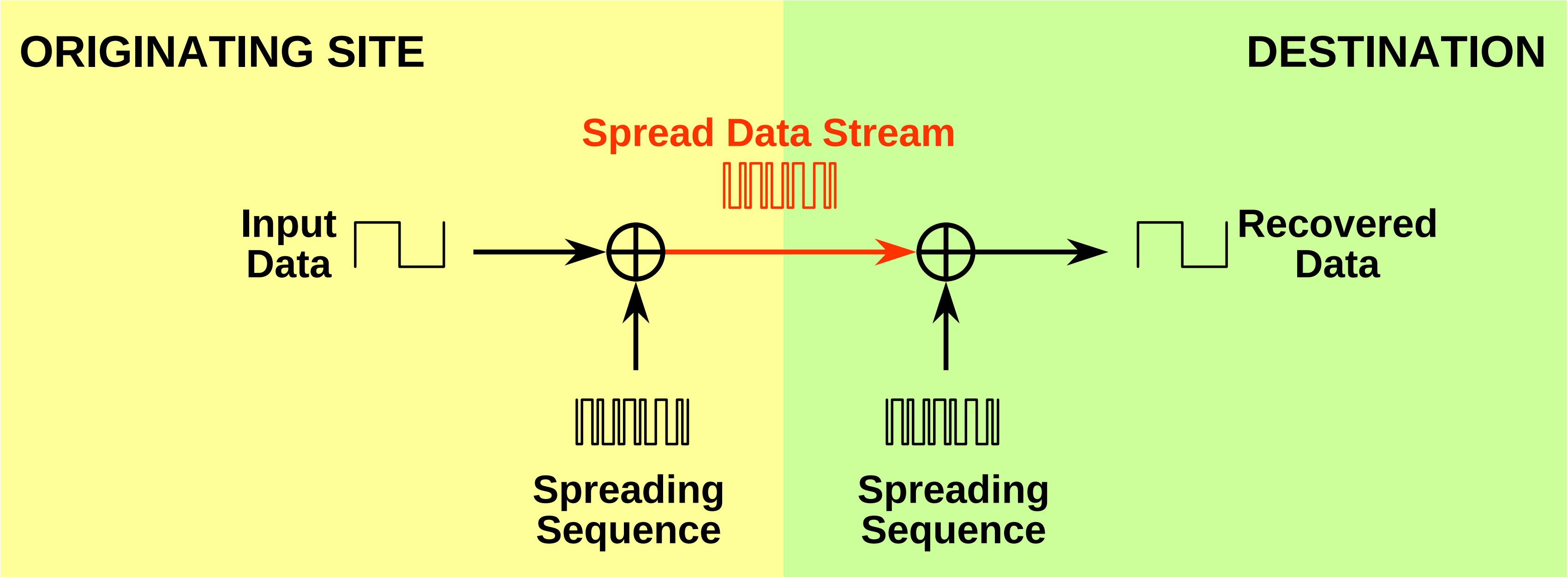


CDMA In Action: Multiple Users on a Sector



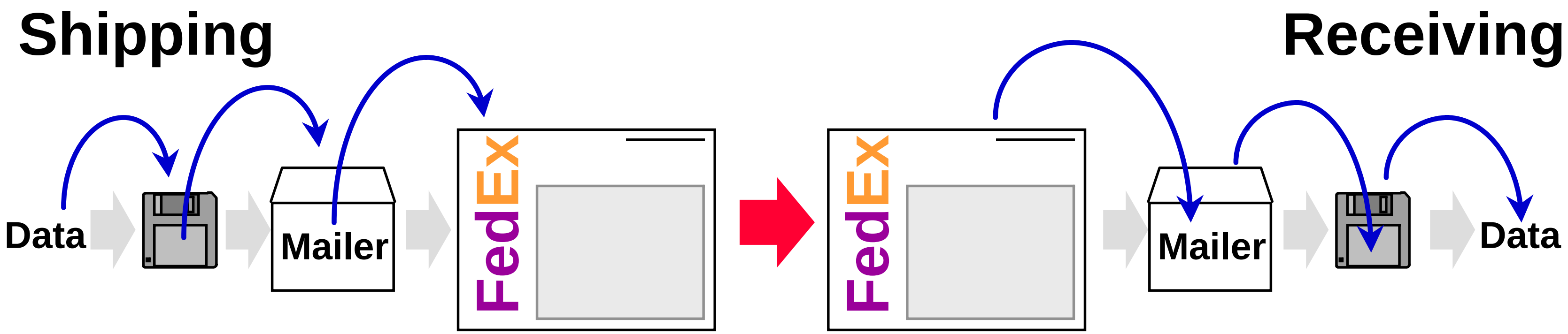
This figure illustrates the basic technique of CDMA signal generation and recovery.
The actual coding process used in IS-95 CDMA includes a few additional layers, as we'll see in following slides.

Spreading: What we do, we can undo



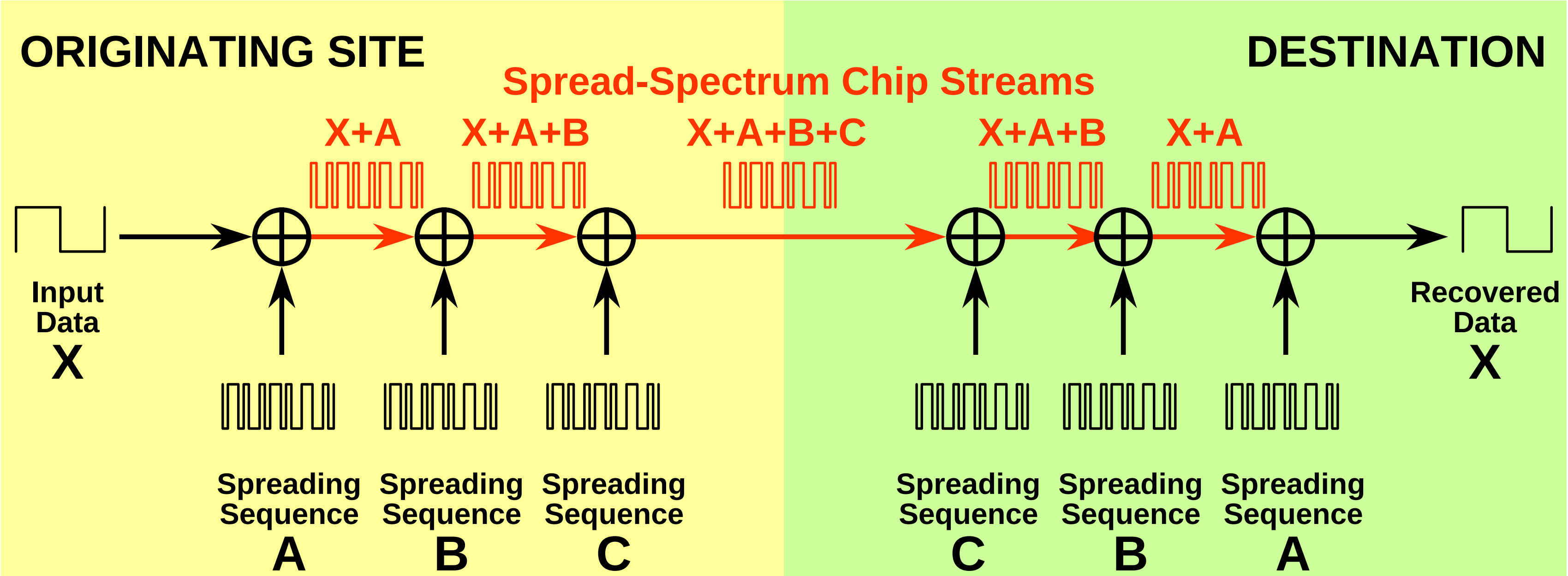
- Sender combines data with a fast spreading sequence, transmits spread data stream
- Receiver intercepts the stream, uses same spreading sequence to extract original data

"Shipping and Receiving" via CDMA



- Whether in shipping and receiving, or in CDMA, packaging is extremely important!
- Cargo is placed inside "nested" containers for protection and to allow addressing
- The shipper packs in a certain order, and the receiver unpacks in the reverse order
- CDMA "containers" are spreading codes

CDMA's Nested Spreading Sequences



- CDMA combines three different spreading sequences to create unique, robust channels
- The sequences are easy to generate on both sending and receiving ends of each link
- "What we do, we can undo"

The Walsh Codes

- 64 "Magic" Sequences, each 64 chips long
- Each Walsh Code is precisely Orthogonal with respect to all other Walsh Codes
  - it's simple to generate the codes, or
  - they're small enough to use from ROM

Unique Properties:
Mutual Orthogonality

EXAMPLE:

Correlation of Walsh Code #23 with Walsh Code #59

```
#23   0110100101101001100101101001011001101001011010011001011010010110
#59   0110011010011001100110010110011010011001011001100110011010011001
Sum   0000111111110000000011111111000011110000000011111111000000001111
```

Correlation Results: 32 1's, 32 0's: Orthogonal!!

WALSH CODES

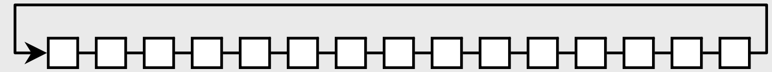
#	64-Chip Sequence
0	0000000000000000000000000000000000000000000000000000000000000000
1	0101010101010101010101010101010101010101010101010101010101010101
2	0011001100110011001100110011001100110011001100110011001100110011
3	0110011001100110011001100110011001100110011001100110011001100110
4	0000111100001111000011110000111100001111000011110000111100001111
5	0101101001011010010110100101101001011010010110100101101001011010
6	0011110000111100001111000011110000111100001111000011110000111100
7	0110100101101001011010010110100101101001011010010110100101101001
8	0000000011111111000000001111111100000000111111110000000011111111
9	0101010110101010010101011010101001010101101010100101010110101010
10	0011001111001100001100111100110000110011110011000011001111001100
11	0110011010011001011001101001100101100110100110010110011010011001
12	0000111111110000000011111111000000001111111100000000111111110000
13	0101101010100101010110101010010101011010101001010101101010100101
14	0011110011000011001111001100001100111100110000110011110011000011
15	0110100110010110011010011001011001101001100101100110100110010110
16	0000000000000000111111111111111100000000000000001111111111111111
17	0101010101010101101010101010101001010101010101011010101010101010
18	0011001100110011110011001100110000110011001100111100110011001100
19	0110011001100110100110011001100101100110011001101001100110011001
20	0000111100001111111100001111000000001111000011111111000011110000
21	0101101001011010101001011010010101011010010110101010010110100101
22	0011110000111100110000111100001100111100001111001100001111000011
23	0110100101101001100101101001011001101001011010011001011010010110
24	0000000011111111111111110000000000000000111111111111111100000000
25	0101010110101010101010100101010101010101101010101010101001010101
26	0011001111001100110011000011001100110011110011001100110000110011
27	0110011010011001100110010110011001100110100110011001100101100110
28	0000111111110000111100000000111100001111111100001111000000001111
29	0101101010100101101001010101101001011010101001011010010101011010
30	0011110011000011110000110011110000111100110000111100001100111100
31	0110100110010110100101100110100101101001100101101001011001101001
32	0000000000000000000000000000000011111111111111111111111111111111
33	0101010101010101010101010101010110101010101010101010101010101010
34	0011001100110011001100110011001111001100110011001100110011001100
35	0110011001100110011001100110011010011001100110011001100110011001
36	0000111100001111000011110000111111110000111100001111000011110000
37	0101101001011010010110100101101010100101101001011010010110100101
38	0011110000111100001111000011110011000011110000111100001111000011
39	0110100101101001011010010110100110010110100101101001011010010110
40	0000000011111111000000001111111111111111000000001111111100000000
41	0101010110101010010101011010101010101010010101011010101001010101
42	0011001111001100001100111100110011001100001100111100110000110011
43	0110011010011001011001101001100110011001011001101001100101100110
44	0000111111110000000011111111000011110000000011111111000000001111
45	0101101010100101010110101010010110100101010110101010010101011010
46	0011110011000011001111001100001111000011001111001100001100111100
47	0110100110010110011010011001011010010110011010011001011001101001
48	0000000000000000111111111111111111111111111111110000000000000000
49	0101010101010101101010101010101010101010101010100101010101010101
50	0011001100110011110011001100110011001100110011000011001100110011
51	0110011001100110100110011001100110011001100110010110011001100110
52	0000111100001111111100001111000011110000111100000000111100001111
53	0101101001011010101001011010010110100101101001010101101001011010
54	0011110000111100110000111100001111000011110000110011110000111100
55	0110100101101001100101101001011010010110100101100110100101101001
56	0000000011111111111111110000000011111111000000000000000011111111
57	0101010110101010101010100101010110101010010101010101010110101010
58	0011001111001100110011000011001111001100001100110011001111001100
59	0110011010011001100110010110011010011001011001100110011010011001
60	0000111111110000111100000000111111110000000011110000111111110000
61	0101101010100101101001010101101010100101010110100101101010100101
62	0011110011000011110000110011110011000011001111000011110011000011
63	0110100110010110100101100110100110010110011010010110100110010110

In CDMA2000, user data comes at various speeds, and different lengths of walsh codes can exist.
See Course 332 for more details on CDMA2000 1xRTT fast data channels and additional Walsh codes.

How the “PN” Codes Are Made, Why They Work

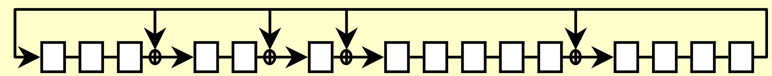
- The CDMA PN (pseudo-random) codes are generated in small shift registers that don’t require much circuitry or much battery power
- Tapped shift register generates a wild, self-mutating sequence 2^N-1 chips long (N=register length)
  - Such sequences match if compared in step (no-brainer, any sequence matches itself)
  - Such sequences appear approximately orthogonal if compared with themselves not exactly matched in time
  - false correlation typically <2%
- The Short PN code is used to make sectors different from each other
- The Long PN code is used to make each mobile’s signal different from other mobiles

An Ordinary Shift Register



Sequence repeats *every **N** chips,* where N is number of cells in register

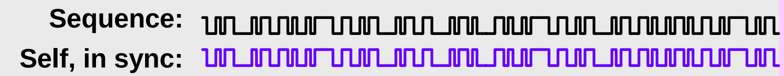
A Tapped, Summing Shift Register



Sequence repeats *every **2^N-1** chips,* where N is number of cells in register

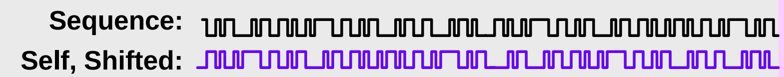
A Special Characteristic of Sequences Generated in Tapped Shift Registers

Compared In-Step: Matches Itself



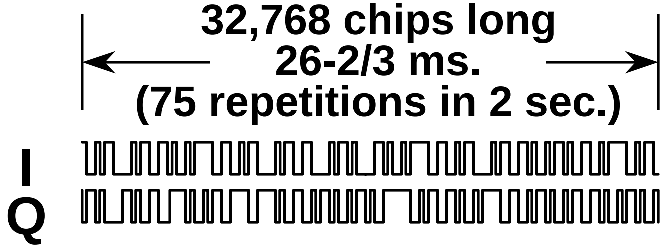
Sum: Complete Correlation: All 0’s

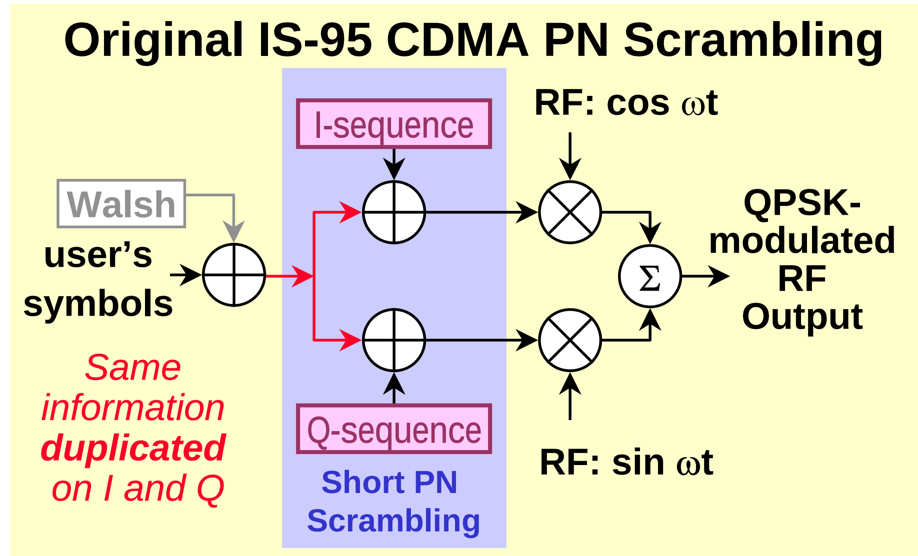
Compared Shifted: Little Correlation

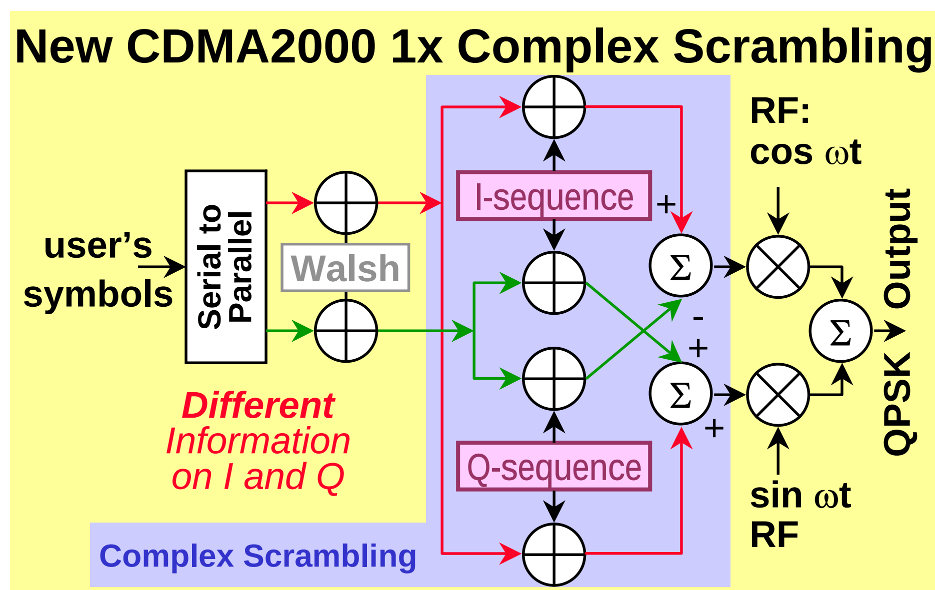


Sum: Practically Orthogonal: Half 1’s, Half 0’s

The Short PN Code makes Sectors Different

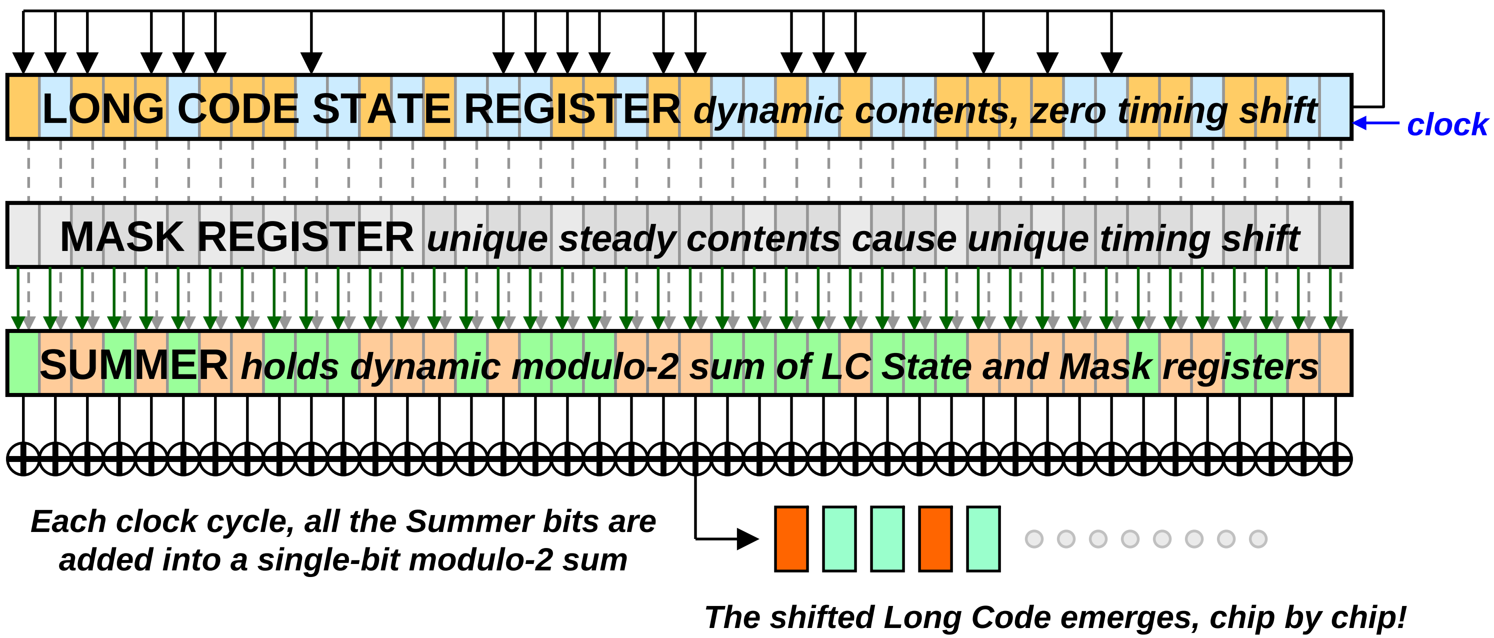






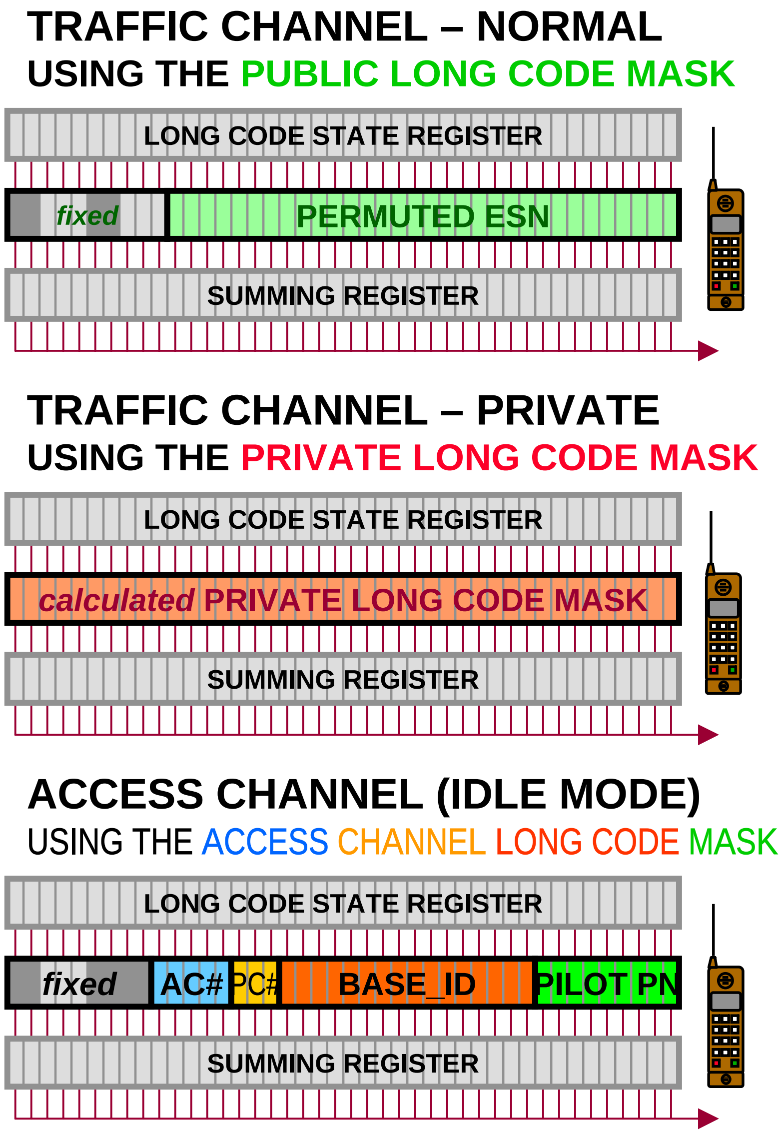
- The short PN code consists of two PN Sequences, I and Q, each 32,768 chips long
  - Generated in similar but differently-tapped 15-bit shift registers
  - the two sequences scramble the information on the I and Q phase channels
- Figures to the right show how one user's channel is built at the bTS

The Long PN Code Makes Mobiles Different



- Every phone and every BTS channel element has a Long Code generator
  - Long Code State Register makes long code at system reference timing
  - A Mask Register holds a user-specific unique pattern of bits
- Each clock pulse drives the Long Code State Register to its next state
  - State register and Mask register contents are added in the Summer
  - Summer contents are modulo-2 added to produce just a single bit output
- The output bits *are* the Long Code, but shifted to the user's unique offset

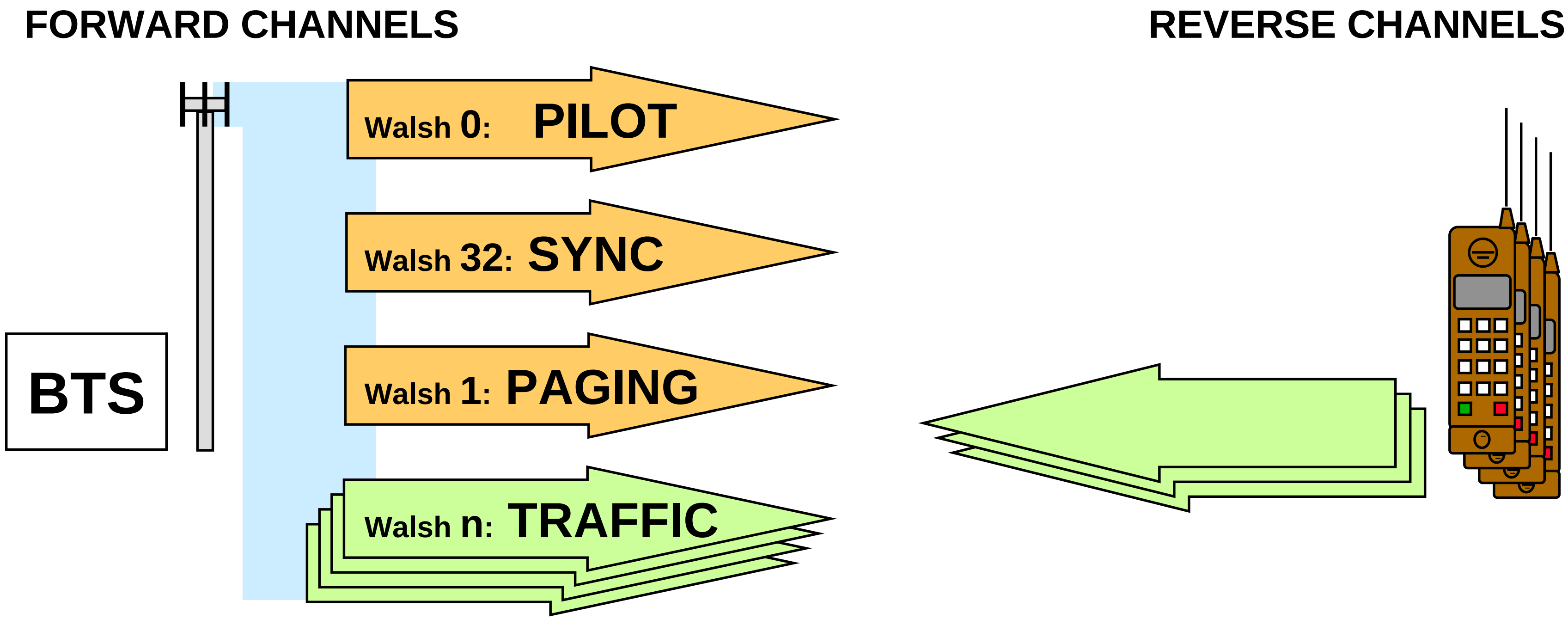
Different Masks Produce Different Long PN Offsets



- Ordinary mobiles use their ESNs and the *Public Long Code Mask* to produce their unique Long Code PN offsets
  - main ingredient: mobile ESN
- Mobiles needing greater privacy use the *Private Long Code Mask*
  - instead of 32-bit ESN, the mask value is produced from SSD Word B in a calculation similar to authentication
- Each BTS sector has an Access Channel where mobiles transmit for registration and call setup
  - the *Access Channel Long Code Mask* includes Access Channel #, Paging Channel #, BTS ID, and Pilot PN
  - The BTS transmits all of these parameters on the Paging Channel

IS-95 CDMA Forward and Reverse Channels

The Channels of 2G IS-95 CDMA



- Existing IS-95A/JStd-008 CDMA offers one radio configuration using just the channels shown above
- IS-2000 CDMA is backward-compatible with this IS-95, but offers additional radio configurations with additional channels
  - These additional modes are called Radio Configurations
  - IS-95 Rate Set 1 and 2 are IS-2000 Radio Configurations 1 & 2